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Relevancy and Risk: The U.S. Army and Future Combat Systems

by Joseph N. Mait and Jon G. Grossman

Overview

In the post-Cold War geostrategic environment, the U.S. Army has been challenged to balance its ability to conduct a major theater war with its requirement to deploy to numerous small-scale conflicts. To realize the capabilities it needs, the Army has proposed a visionary transformation of light infantry and heavy armored forces into medium-weight forces capable of fighting the full spectrum of military conflicts. Key to this transformation is the development of the Future Combat Systems (FCS), which depends on substantial improvements in six critical technology areas: sensors, networks, robotics, survivability, lethality, and power sources.

In assessing these critical technologies, we found a wide range of estimates concerning the technologies' maturity and applicability to FCS. Using open literature sources, we found that technology demonstrations in the six areas needed to support a milestone B decision (scheduled for 2003) could not occur until 2004 at the earliest or as late as 2010. Estimates for when the technologies could be ready for FCS low rate production varied from 2006 to 2015.

The uncertain maturity of these technologies does not mean that transformation is not technically feasible. Rather, innovative management of technical risk is required. We recommend developing initial versions of FCS for low-intensity conflicts and, as technologies mature, new versions for higher-intensity combat.

In the decade since Operation *Desert Storm*, the Army has pursued sequentially three distinct visions: digitization, preservation, and transformation. Each represents what the Chief of Staff of the Army (CSA) believed to be the best solution to the Army's most important problems. The first vision, developed under General Gordon Sullivan (1991–1995), was to digitize forces for "third-wave warfare."[1] As a consequence, the Army now has significant heavy (armored) forces that are digitized. Light forces recently started their own digitization efforts, and the first operational digital infantry battalion is expected in 4 years. The second vision, captured in the phrase "soldiers are our credentials," was a pragmatic attempt by General Dennis Reimer (1995–1999) to retain as much force structure as possible in an era of declining budgets. During this time, significant numbers of expensive forward-based units were either retired or repositioned back to the United States.

These two visions, formulated in response to the national defense posture of fighting and responding simultaneously to two major theater wars (MTWs), yielded an Army that is both a continental-based force of heavy lethal forces of limited deployability but capable of winning against conventional, mechanized armies and a light, readily deployable force with limited staying power. However, the probability of another MTW, such as *Desert Storm*, actually decreased during the 1990s, while the changing geostrategic environment and growing unreliability of conventional deterrence in the Third World has increased the occurrence of small-scale contingencies. Organized violence has become the norm around the globe in such diverse places as Chechnya, Colombia, Kosovo, and Palestine.

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Outbreaks of organized violence have dramatically increased the number of American military deployments to small-scale conflicts, frequently in regions where the infrastructure for heavy mechanized vehicles is extremely restricted or practically nonexistent. The Navy, Marine Corps, and Air Force are inherently capable of responding rapidly to small-scale overseas crises. The Army shaped by the Sullivan and Reimer visions, however, is not, and its relevance in the new environment has been questioned.

To address the Army response to future threats, Chief of Staff General Eric K. Shinseki in fall 1999 presented his vision to transform the Army by stages over a 30-year period into a force that would be strategically responsive and dominant across the full spectrum of operations. This Objective Force is intended to close the gap between light and heavy forces by replacing them with medium-weight forces designed both to deploy quickly to fight an MTW and to perform peace-enforcing missions. The transformation vision keeps and, in many cases, enhances the Army's ability to fight major wars yet creates rapidly deployable units that, if successful, will eventually predominate in the future force structure. This vision, however, is not easy to implement and relies heavily upon technology. Thus, how technology is used and managed is critical to its success.

Almost all military transformations have been enabled by innovative uses of new technology. The technology can be as simple as the glass jars that allowed Napoleon's troops to store food safely for long periods of time and thereby remain in the field longer than their opponents or as complex as the nuclear weapons that ended World War II, which required the creation of new fields of science and engineering. The right combination of the visionary with the possible is critical to successful transformation.

Much of the focus on Army transformation has been on the development of the Future Combat Systems (FCS). Through their appearance in news headlines, the FCS have captured the interest of the American public. Because weapons are often the visible symbol of a complex process of change, public fascination with the futuristic capabilities of the FCS is understandable. However, concerns exist that critical FCS technologies will not have advanced significantly by 2003, when the decision (known as Milestone B) whether to proceed with a demonstration program will be made. Some believe that a decision at that time would be, at best, a guess.

We rely upon open literature sources to examine some of the challenges facing the development of critical FCS technologies and assess when each technology may become viable. We then consider Army management of transformation in the face of uncertainty. To do so, we adopt the posture of a potential investor (Congress, for example) and pose slightly modified versions of the questions that venture capital firms ask before investing.

Venture capital firms invest in companies capable of managing risk. The soundness of the Army's vision should not be assessed in terms of absolutes but in its consideration of risk. However, managing risk does not create the technology breakthroughs required for the FCS. It allows the Army additional time to make better-informed decisions. The viability of the FCS still needs to be made. In the last section, we summarize our findings and conclude that the tiered approach to FCS development being pursued will enhance Army capabilities and help realize its transformation vision.

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The Transformation Plan

The Army's Transformation Campaign Plan charts a course for change yet maintains current readiness to execute operational requirements in support of the National Military Strategy and requirements from the commanders in chief. The Army transformation process has been influenced by four factors: the conduct of future war, the future operating environment, the increasing significance of full-spectrum operations, and the anticipated diminished flexibility of the current legacy force. Together, these factors have assisted the Army in evoking both evolutionary and revolutionary change in its force structure. The service is taking a balanced approach to change by capitalizing on new technology while maintaining and improving its legacy warfighting capabilities.

The Interim Force is the vanguard of the transition from a legacy to a future force and consists of legacy forces plus six medium-weight interim brigade combat teams (IBCTs). The IBCTs are built using off-the-shelf equipment to meet a near-term strategic requirement for deployability that is now absent. The IBCTs operate as part of the current Army division structure and provide complementary capabilities for both heavy and light units. Two IBCTs at Fort Lewis are the lead units for filling this gap. In addition to developing tactics, techniques, and procedures (TTPs) for the Interim Force, they are refining requirements and developing initial TTPs for the Objective Force.

The character of the Objective Force directly addresses the changes in the geostrategic environment. It is designed to integrate the best information technologies from the ongoing revolution in military affairs and to provide the requisite rapid deployment to distant and austere theaters to meet the challenges of 21st-century expeditionary requirements. To meet the Army goal of a force that is strategically responsive and dominant across the spectrum of military operations, the Objective Force is expected to be agile, versatile, lethal, survivable, responsive, deployable, and sustainable.

Future Combat Systems

The importance of the FCS to the Objective Force is underscored by the Army's increased investment in science and technology to accelerate FCS development. In February 2000, the Army signed an unprecedented $916 million memorandum of agreement with the Defense Advanced Research Projects Agency (DARPA) for fiscal years 2001–2005, within which DARPA is responsible for pursuing high-risk innovations, and the Army is responsible for accelerating the development of its high payoff core technologies.

Essential to satisfying the requirements of the Objective Force, the FCS should be lightweight, deployable, and maneuverable. To achieve this, the FCS is intended to be not platform-centric but network-centric. The FCS is a modular construct with its separate

functions for fires, transport, and sensing distributed across platforms that are individually smaller and lighter than either the 70-ton M1A1 Abrams tank or 35-ton M2A3 Bradley fighting vehicle. The FCS consists of both manned and unmanned ground vehicles (UGVs), as well as unmanned aerial vehicles (UAVs), in a network-centric system of systems.

In May 2000, DARPA and the Army selected four teams for the initial FCS conceptual design phase: Boeing Phantom Works, Team Full Spectrum (SAIC), Team Gladiator (TRW, Lockheed Martin Missiles and Fire Control, CSC/Nichols Research, Carnegie Mellon Research Institute, Battelle Memorial Institute), and Team Focus Vision Consortium (Raytheon and General Dynamics Land Systems). Each team was to deliver a single design by 2003. The teams were free to consider designs without any restrictions on composition, but had to satisfy certain global criteria:

- weight less than 20 tons (C–130 transportable)
- 33–50 percent decrease in logistics sustainment requirements
- 50 percent decrease in fuel consumption
- 96 hours rapid response
- 5 days operating tempo operation without resupply
- 100 kilometers per hour (kph) burst speeds
- 60 kph cross-country sustained speed

In addition, the FCS must be able to survive a first-round engagement, it must be affordable and maximize commonality as well as joint and international interoperability, and it should include embedded training and human factors considerations in its design.

The work of the original four teams ended when the FCS acquisition schedule was advanced and the joint team of Boeing and SAIC was selected in March 2002 as lead systems integrator (LSI) responsible for overseeing the integration and demonstration of an FCS prototype. The initial concept and technology development phase extends from March 2002 to June 2003, during which time the LSI is to develop a system of systems architecture, performance specifications, and material concept for the FCS and support the Training and Doctrine Command in refining operational concepts and user requirements. In April 2003, the decision will be made whether to proceed toward the system development and demonstration (SDD) stage, which is scheduled to extend from March 2003 to September 2006.

The timetable for future decisions and milestones calls for a decision on low-rate initial production in fiscal year (FY) 2007 and full-rate production in FY08 or FY09. Finally, a demonstration of initial operating capabilities is expected in 2010 with subsequent iterative, or block, upgrades to full operational capability thereafter. Analogous to computer and software upgrades, the block upgrades improve capability without having to replace the platform.

Systems Requirements

The criteria used to arrive at a decision at each milestone are critical. To formulate that decisionmaking process ourselves, we created baseline requirements (see table on page 4) for mobility and deployability, survivability, lethality, and situation awareness using defensive and offensive military missions. Some requirements follow from the conditions stipulated by the Army and DARPA. For example, the fuel efficiency of the M2A3 Bradley is about 1.5 miles per gallon (mpg); therefore, to reduce fuel consumption by half, the FCS must realize 3 mpg. Other requirements are first-order estimates. For example, the load and logistics package over a 5-day period for a Bradley in heavy combat is approximately 3 tons. The majority of this weight is in munitions, with fuel as the second major contributor. To accommodate this load, each FCS ground vehicle must weigh between 16 and 18 tons.

In setting the requirements, our goal is not to be precise but to be sufficiently accurate to allow for an objective, technological assessment of FCS capabilities. (For example, the current C–130 with fuel can actually lift only 16 tons, the C–130J even less.) Our requirements provide a foundation for this discussion and a point of reference for future ones.

Systems Technologies

We now consider six basic technologies that contribute to meeting the criteria listed in the table: sensors, networking, robotics, armor, munitions, and hybrid power. We chose these six because of their importance to enabling FCS capabilities. The former three are enabling technologies that cut across FCS capabilities while contributing directly to situation awareness. The latter three address directly FCS survivability, lethality, and deployability.

The reliance of the FCS on electronic information can be summed up succinctly. Shooting first and hitting a target precisely with lethal munitions is key to FCS survivability. However, ensuring timely knowledge requires the resolution of latency issues (for example, sensor-to-shooter time) to allow striking a target from an extended range.

Sensors. Electronic information is used both as an additional weapon in the FCS arsenal and as an additional layer of protection. On the surface of this protective layer are tactical sensors (for example, chemical, acoustic, electro-optic, infrared, electromagnetic, and magnetic). National assets alone are insufficient to meet the intelligence, surveillance, and targeting requirements, especially the update rates, indicated in table 1. High-altitude electro-optic and electromagnetic sensors are relatively mature assets available to division-level commanders and above. However, typical update rates are on the order of hours to a day and are therefore most useful only for intelligence preparation of the battlefield.

To truly enable FCS capabilities with fast update rates, sensors and sensor platforms need to be assets of brigade-level and lower commanders. Commanders are currently able to detect and track targets using unattended acoustic ground sensors and moving target indicator radars, but reliable target identification requires imaging sensors mounted on UAVs and UGVs. Simply mounting a visible or infrared camera on a platform, however, does not solve the target identification problem. Bandwidth constraints of the network do not allow for streaming video from these sensors, nor would the flood of data help a commander assess the threat situation.

Miniaturization of electronic technology and its integration with photonic technology will be necessary to provide UAVs and UGVs with on-board processing for data compression or information extraction. In this way, the sensor provides a commander only what is required under the low-power, low-bandwidth constraints of the network. A demonstration of such technology under the Army's Sensor Optoelectronic Processing Scientific and Technology Objective (STO)[2] is

expected in FY04, but its insertion into a systems demonstration is unlikely before 2006. Concurrently, the Sensors for the Objective Force STO, which addresses the integration of sensors into a network, has been proposed as an advanced technology demonstration (ATD). The objective of the ATD is to demonstrate sensor management tools for sensor interaction and cross-cueing using ground and aerial platform-mounted sensors. Initiation of the ATD in FY02 indicates a final demonstration of capabilities no sooner than FY05.

However, the utility of sensor data depends upon the speed with which it can be relayed to and processed by other components in the FCS. In one engagement in *Desert Storm*, sensor-to-shooter time was 80 minutes after an SA–2 site was detected as a potential threat. Although in the recent military operations in Afghanistan, sensor-to-shooter times were reduced to 20 minutes, nominal times remained on the order of hours. Perhaps the greatest challenge facing FCS is the development of a network to provide high-speed command, control, and communications.

Networking. FCS network capabilities go beyond those envisaged for the Army's current Battle Command System. The network must be capable of integrating numerous remote ground and aerial sensors, maneuvering robotic systems, and controlling and directing both direct fire and beyond-line-of-sight weapon systems and of doing so in a mobile environment. In addition, bandwidth management and seamless internetworking of both horizontal and vertical communications are required. The architecture and protocols for such a system are presently undeveloped and are only just being addressed.

Anyone who has used a wireless modem or cell phone to connect to the Internet is already aware of the problems facing the FCS. Consider that Single Channel Ground and Air Radio System (SINCGARS), which has a bandwidth of only 9.6 kilobits per second (Kbps), would take 23 minutes to transmit a single 1001 x 1650 pixel 8-bit JPEG image. The Enhanced Position Location Reporting System (EPLRS), which transmits at 14.4 Kbps, would still take more than 15 minutes. Only a broadcast system, such as the Global Broadcast Service, which transmits at 23 megabits per second (Mbps), is capable of transmitting this image in under 1 second. The FCS is required to transmit images and data from multiple sensors, which only exacerbates the bandwidth problem. Although image compression and partial information updates can reduce the bandwidth load, to maintain situation awareness on the order of tens of minutes dictates a constant large stream of imagery and data.

Furthermore, mobility requires robustness (that is, the network must be insensitive to nodes dropping on and off the network unexpectedly), which places an additional burden on network protocols. In addition, the network must have a low probability of detection and intercept and must provide assured communication that is linked horizontally and vertically.

The Army Multifunctional On-the-Move Secure Adaptive Integrated Communications (MOSAIC) ATD addresses some of these hurdles.[3] By 2004, it is expected to demonstrate a self-organized wireless cluster consisting of 15 to 20 nodes. The network is expected to have a 2-minute installation time and 5-minute recovery. Data transmission is between 56 Kbps and 15 Mbps, dependent upon the range between nodes, which at the extremes are from 100 kilometers (km) to 100 meters. However, a wireless network with the capacity for 100 Mbps transmission will not be ready until at least 2010.

Future Combat Systems Requirements

Mobility and Deployability
Weight: less than 18 tons
Fuel efficiency: greater than 3 miles per gallon
Burst speed: 100 kilometers per hour
Cross-country speed: 60 kilometers per hour

Survivability
Frontal 60 degree arc:
- Single kinetic energy round from T/80–T/72
- Multiple rounds from 20–25-mm chaingun

Hemispherical:
- 50-caliber machinegun
- 2–3 antitank guided missiles
- rocket-propelled grenades

Antitank mines

Lethality
Conventional targets:
- T72 and T80 main battle tank
- Bunkers and hardened buildings (for example, military command posts)

Post-Cold War Requirements:
- Precision strike
- Low collateral damage
- Specific individuals and groups

Situation Awareness (goals in open terrain)
90 percent of all tanks, armored fighting vehicles, and artillery positions known and updated every 10–30 minutes
70 percent of enemy infantry positions known and updated every 5–10 minutes
90 percent of blue force infantry positions known
95 percent of noncombatants identified
- Potential Combatants also identified

Robotics. Advances in electronics enable FCS capabilities not only in information but also in robotics. As part of the FCS concept, robotic vehicles serve several functions, including as sensor platform, weapon platform, and network node. As demonstrated in Operation *Enduring Freedom*, UAVs are mature enough to serve as semiautonomous sensors and weapons platforms. Because of the complexity of ground navigation, UGVs are not as far along.

Although the operational concept for FCS requires UGVs to sense the battlefield and react on their own with minimal human interaction, current technology can best be described as remote-controlled or teleoperated. Semiautonomous operation, suitable for sensing and indirect fire functions, will not be available until 2010, and fully autonomous systems (necessary for direct fire, battle damage assessment, and reconnaissance, surveillance, targeting, and acquisitions) will not be available until 2015 or later.[4]

The Army's Robotic Follower ATD[5] addresses the critical need for algorithms that can provide autonomous navigation. The goal of the ATD is to enhance UGV technology as a follower—in essence, to create a robotic replacement of the Army mule. In off-road conditions, the robotic follower follows 500 meters behind a lead vehicle at 15 kph. By 2005, separation is expected to increase to 750 meters and speed to 65 kph.

The requirement that all ground vehicles weigh less than 20 tons and fit inside the C–130 "crucible" places its greatest burden on those technologies that enhance survivability and lethality. The FCS dependence upon robotic vehicles addresses the survivability of soldiers by removing them from harm's way. Further, without having to

make room for a human operator, a robotic vehicle can be designed closer to the ground and smaller than a manned vehicle, which presents a smaller silhouette to an enemy and enhances the survivability of the platform. Manned vehicles will require innovative passive and active armor to enhance soldier survivability.

Armor. Survivability in the conventional sense of surviving a fired round requires technologies in passive and active protection, as well as stealth. With regard to passive protection, improvements in armor technology have led to the development of ceramic- and composite-based lightweight armors capable of surviving a first-round hit from a medium-caliber weapon (smaller than 30 mm, as compared to a 125-mm round for the M1A1). The technology to manufacture these armors for application to FCS should be available by 2006.

In contrast to passive armor designed to withstand a hit from a round, active protection systems are designed to sense the round and deflect or destroy it prior to penetration (using, for example, ejecting armor plates to alter trajectory) or defeat it after penetration. Deflection of shaped-charge weapons and rocket-propelled grenades should be possible beyond 2006, but the deflection of larger munitions or kinetic-energy rounds is not expected until beyond 2010 and perhaps not before 2015.[6] The dependence of FCS survivability upon sensors is underscored by their role in active protection systems; however, in contrast to long-range sensors (that is, tens of kilometers), their application here is at an immediate level (that is, out 2 kilometers). Further, the vulnerability of a lightweight platform to mines increases the need for countermine sensing.

More advanced protection technologies, such as stealth, are also not expected to mature until 2010. How one can apply these technologies to ground vehicles is understood from basic principles, but their practicability on a large scale must be tested. The development of smart armor, which attempts to deflect a round once it has penetrated the first layer of armor, and electromagnetic armor, which reshapes a penetrated round, are also research areas that will require a decade or more to bring to fruition.

As mentioned above, munitions and fuel are the major contributors to the weight of a 5-day load. Thus, the development of smart munitions and increased fuel efficiency are necessary to reduce this load from 3 to 1.5 tons. The last two technology areas that we address are therefore weapons and hybrid power systems.

Munitions. To enhance survivability, FCS fires will be distributed and robotic and will rely heavily upon non-line-of-sight systems. Lethality overmatch will be guaranteed through an integrated system of both ground-based line-of-sight and non-line-of-sight systems, as well as precision and loitering attack missiles.

A demonstration of ground-based systems is addressed in the Multirole Armament and Ammunition ATD.[7] The ATD admittedly places an emphasis on the demonstration of an improved kinetic energy (KE) round by 2006. In contrast to conventional munitions that rely upon explosives, a KE round destroys a target through energy transfer. The intent is to transfer sufficient energy to destroy a target by blasting a penetrator rod traveling at hypervelocity speed (5,000 feet per second) through heavy multiplate or reactive armor.

The effectiveness of KE weapons has already been demonstrated by the line-of-sight antitank (LOSAT) missile. LOSAT consists of two 2-pack launch pods mounted on a Humvee and uses a second-generation infrared imager for target acquisition. By the end of FY03, an operational company of 144 missiles will be delivered to the XVIII Airborne Corps.

Improvements in KE missile technology are covered under the Direct Fire Lethality ATD, which addresses the loss in accuracy due to lateral acceleration and diminished performance against explosive reactive armor. The goal of the Direct Fire Lethality ATD is to increase a KE round's probability-of-hit and probability-of-kill at 3 km to better than 70 percent of the current Abrams rates. Minimum acceptable performance is a 30 percent improvement. The primary hurdles to improved performance are not technological but engineering and manufacturing. Technologies being pursued include an advanced propellant, a radial thruster, a novel penetrator, and an electro-thermal-chemical igniter. The improved KE missile will transition to the Armament and Ammunition ATD in 2002.

The Armament and Ammunition ATD[8] addresses issues related to the overall firing systems relative to FCS goals. For example, current gun weight is 6,700 pounds (lbs), which should be reduced to 2,900 lbs by 2006. Weight reduction to 3,500 lbs is acceptable. Further, the lightweight FCS platforms need to withstand the recoil force of the weapon system, which currently is 160,000 lbs of force. The goal of the ATD is to reduce this to 85,000 lbs, with 100,000 lbs as an acceptable minimum.

Beyond-line-of-sight and non-line-of-sight weapon systems are currently not as mature as line-of-sight systems. To address this, DARPA initiated the Netfires program, which seeks to develop a multi-missile package capable of engaging targets between 25 and 50 km away, as well as a soft-launched loitering attack missile capable of hitting targets between 40 and 100 km away. The loitering attack missile can remain above a designated area for up to 1 hour before engagement while it collects data to improve situation awareness. These technologies will not mature before 2006.

Hybrid Power. With respect to mobility and sustainability, we note that robotic vehicles are inherently more easily deployed than manned vehicles because they can be smaller and lighter. These characteristics will no doubt contribute to improving fuel efficiency, but additional improvements can be realized using hybrid power systems, such as standard hydrocarbon propulsion technologies combined with electronic drive systems.

A hybrid system combines an energy storage system (for example, flywheels or batteries), a power unit like a fuel cell, and a vehicle propulsion system. Propulsion can come either entirely from an electric motor alone, referred to as a *series configuration*, or in combination with the engine in a parallel configuration. One attractive feature of using hydrogen fuel cells for power generation is the production of water as a byproduct. Thus, in addition to reducing fuel consumption, fuel cells reduce water requirements as well.

Hybrid electric counterparts of both the Bradley and Humvee are already under development. With regard to the FCS, the Advanced Hybrid Electric Drive (AHED) Technology Program seeks to demonstrate a 13-ton, 8-wheeled vehicle using an 8-wheel drive (8 x 8). The independent wheel drive, which uses a 150-horsepower (hp) permanent magnet motor, allows a vehicle to turn in place like a tank by having one or more wheels turn in different directions. The primary power source for the AHED is a 500-hp diesel engine and a 114-kilowatt (kw) battery pack. It has a 114-kw battery pack for supplemental power. Top speed is expected to be 65 mph.

Many of the technologies associated with hybrid power remain research topics. For example, hybrid propulsion of FCS ground vehicles requires efficient electronic switching at high voltages and temperatures. Increase of efficiencies to the levels desired for the FCS requires a better understanding of surface interfaces and material defects in wide bandgap semiconductor materials, a fundamental research issue that may not be resolved before the decade's end.

Assessment

The Army is moving at a fast pace to address the goals for transformation. But, like a good business, the Army must constantly evaluate its efforts to ensure it is on the right course. Unlike a company, the Army is not allowed to fail and go out of business. In the course of transformation, it is therefore critical for Army leadership to be ready at all times to answer several basic business and national security questions. We present five questions a Congressional investor might ask. We also present what we believe are the current answers.

Is the Army making the key decisions for its future at the right time? Are 2003 and 2006 too soon to make key technological decisions?

A criticism of the Objective Force is its heavy reliance on breakthrough technologies for success. To address this, we return to table 1 armed with the discussion of the previous section. In fact, the capabilities in the Army vision do not rely heavily on leap-ahead technologies. Although the revolutionary capabilities envisioned for the FCS require as-yet-undeployed electronic technologies, critical capabilities in survivability and lethality depend on more conventional technologies. This bodes well for the demonstration of a prototype FCS between 2003 and 2006 with rudimentary capabilities in networked situation awareness but with more substantial capabilities in survivability and, especially, line-of-sight fires. Our assessment indicates a block I FCS entering low-rate initial production in 2007 would be capable of peace-enforcing and low-end small-scale conflicts.

Robotics is a keystone technology for the FCS. The use of robotics protects soldiers' lives and provides opportunities in vehicle design that lend themselves to enhancing platform survivability, deployability, and mobility. The dependence upon robotics is perhaps the key enabler to reducing overall FCS weight and size.

Although present capabilities in UGV technology fall short of FCS expectations (for example, a 15-kph follower as opposed to a 60-kph fully autonomous vehicle), the development path is straightforward and will be aided by natural advances in software and computing technology (for example, more powerful microprocessors and increased memory capacity in a constant volume). But the present deficiencies in UGV technology are offset by the maturity of UAV technology and the approach to Netfires.

While reducing vehicle weight is important, it may be possible to achieve the Army's goal of deploying an FCS brigade in 96 hours using a mix of robotic and manned vehicles that does not rely solely upon the C–130 aircraft. A wide range of other deployment enablers exist that can meet the strategic timelines. For example, the C–17 strategic airlifter is capable of moving combat vehicles up to 70 tons. Hence, even if technology cannot achieve the 20-ton objective, heavier variants can still be deployed.

The information requirements for detecting, tracking, and identifying objects are immense, and the network bears the burden. Sensor technology needs to be miniaturized and, due to network and FCS constraints, needs to be smart (that is, provide on-sensor preprocessing for detecting and tracking targets prior to transmission). Although the technology for achieving this no longer lies in the realm of research, this does not imply that solving the engineering problems is a simple task. The infrastructure for developing and producing it needs to be supported.

The performance of the MOSAIC ATD network will be critical in assessing the level of situation awareness that is possible in the near term. It should not be surprising that the most revolutionary technology—network technology—has yet to be demonstrated. The challenges in designing a secure network with mobile infrastructure are unique to the military. However, commercial technology developed for networks with fixed or portable infrastructure can be leveraged for military needs, especially with regard to integrating applications that are presently stovepiped. Doing so though requires a military transformation, not in strategy or technology, but in acquisition. Present acquisition speed is well matched to the pace of change in conventional military technologies but not to a doubling in capacity every 18 months described by Moore's Law.

In most cases, the path from enabling technology to development is clear and straightforward and probably would have been pursued even without the introduction of the FCS. Thus, the FCS gives the Army technical community a banner to follow. But the FCS is not simply a rallying symbol for technology development; it also represents a major procurement by the Army. In this respect, the Army's vision is more similar to President John Kennedy's goals for the manned U.S. space program in the 1960s than it is to the contemporaneous *Star Trek* view of the future.

Are the milestone being made too soon? There certainly are nontechnical risks associated with delaying a procurement action. Due to other competitive costs for recapitalization of the legacy fleet of Army equipment, the requisite procurement dollars may not be available in the out years. An the political environment may not support a change in Army force structure in 10 years. However, as the technical assessment indicates, demonstration of rudimentary FCS capabilities relies upon overcoming engineering hurdles, not research ones.

Does the transformation of the Objective Force rely too heavily upon new technology for the survivability of the FCS?

This is an important question since threat forces in the future may rely upon heavy, armored formations to counter the future Objective Force. Throughout the history of warfare, mass has a demonstrated unique quality all its own when it comes to the sustained prosecution of decisive, close combat. FCS assumes a proactive stance with regard to its survivability. That is, the FCS denies an opponent the opportunity to fire by seeing first and shooting first. Also, the likelihood that an opponent might hit a manned vehicle is reduced using distributed, unmanned platforms on the battlefield.

Critics of the Army contend that by relying upon a mobile, light, and distributed force structure, the Army is subjecting itself to far too many dangerous situations where large-scale heavy forces will be required. Lethal technologies and precision weaponry, while effective, may still prove incapable of defending the lightweight platforms

of the FCS against a determined adversary. However, getting hit on a future battlefield very probably means being killed, which is the case even today. The argument for FCS rests less on its individual combat power relative to a heavy enemy force and more on its place within the Army's contribution to a joint services operation.

Nonetheless, to address some of these issues concerning survivability, the Army has purposefully dedicated one modernized legacy corps, the III Corps at Fort Hood, Texas, to retain a sufficient number of heavy combat systems, such as the M1A2 Abrams tank with system enhancement package, the Paladin self-propelled howitzer, the multiple-launched rocket system, the Apache Attack Aviation system, and the M2A3 Bradley fighting vehicle. The Army contends that these Big Five combat systems will remain available until the 2030 timeframe to ensure that no heavy competitors surprise the Army.

Even with one corps as an insurance policy, the question remains: How vulnerable is FCS? With the possibility of near-peer competitors, such as China, able to deploy several corps' worth of combat power, how survivable will the Objective Force plus one corps be in terms of the future threat? Additional study is required to address survivability. Our assessment indicates that survivability against small arms and light weaponry will soon be possible. Given this level of conventional survivability, to ensure unit survivability against a force with heavy weaponry, the development of strategy and tactics through wargaming and simulation is required.

Given the uncertainty in survivability, as well as the uncertainty in future threats, are the costs for the FCS worth the investment?

A basic case for FCS investment can be made in terms of the network. Michael O'Hanlon argues that military transformations make sense only when technology and new concepts and tactics are ripe.[9] The maturity of network technologies, like the Internet, that we are so accustomed to in our daily lives makes it natural to want to apply them to the battlefield. The Transformation Campaign Plan and the FCS provide a means for the experimentation necessary to develop the requisite concepts and tactics.

Army transformation counts upon advances in a mature command, control, communications, computer, intelligence, surveillance, and reconnaissance (C^4ISR) network to improve Objective Force combat effectiveness. This network includes the use of military communication satellites, Global Positioning System satellites, Global Hawk UAVs, A–160 (Hummingbird) UAVs, and a base station gateway to collect and transmit sensor data as well as to communicate. While some components already exist independently, the fusion of sensor information in an Internet grid is a truly important advance in military technology. Because the future Objective Force may be capable of finding and fixing threat weapon systems at greater ranges, beyond line of sight, it makes good sense to invest in this long-range enhancement to current warfighting capabilities.

Is the Army accepting too much strategic risk in the near term? Has it built in strategic hedges to account for mistakes in judgment?

Any serious discussion of future capabilities should include a thoughtful discussion of strategic risk. Whenever tradeoffs are made between current and future force structures, risks need to be articulated and considered in the process of transformation. Unfortunately, when discussing the future security environment for the next 30 years, one thing is clear: the future is uncertain. It remains uncertain in terms of the potential rise of a near-peer competitor, economic predictions for the United States, potential adversaries in the Third World, changing developments in the workforce, and the advent of disruptive technologies that may make the FCS obsolete. With these variables in mind, few militaries would favor the investment in large-scale procurement of specific weapon systems that might have decreasing utility over the long term.

Critics argue that the Army should not increase its strategic deployability to cope with the increasing number of short-notice challenges across the spectrum of conflict. In particular, some note that the Army's rapid deployment may be akin to the more speedy dispatch of General Custer and his troops to the Little Big Horn. The Army, they claim, may be walking into a strategic ambush. Critics are concerned that the new Army will lack the staying power to survive in faraway places where the Objective Force must fight in situations where it is vastly outnumbered and distant from viable reinforcements. Other critics argue that the Army should not be quick to respond to crises abroad and instead should rely upon a gradual approach to conflict escalation before committing precious American ground troops abroad. Indeed, speedy deployments may then become a self-fulfilling prophecy. The problem with developing the capability, they argue, will be that the U.S. military will be more likely to use it in the future.

To counter these arguments, others note that the development of the FCS progresses in stages, or block upgrades, as technologies mature. The first inception of the FCS will reflect many of the technologies discussed. As these are integrated and tested, technologies that are now moving from research laboratories into development, like photonic interconnects, will be readied for deployment in the first upgrade.

The block upgrade approach to FCS development implies that it is flexible on a technical level. We argue that the block upgrade approach also provides the mechanism for making the FCS flexible on a strategic level. If the FCS is used only in those situations for which its capabilities are well suited, it is possible to mature the FCS with each upgrade from an instrument of peacekeeping to one capable of fighting in a major theater war. The time between upgrades allows planners to assess emerging threats, determine a response to them, and develop new strategies and tactics given the present state of the FCS. Thus, the Army's vision can be a "moon shot" for strategists as well as technologists.

Is the Army changing too quickly to handle the transformation?

Changing too quickly can create dilemmas for any organization. Often these changes adversely affect the personnel who have to cope with rapid adjustments to their environment. Can soldiers of the 21st century adapt to the new challenges of quicker reaction times in dealing with their adversaries? Do leaders and subordinates have the requisite multifunctional and information technology skills to employ their new capabilities? Is it possible to retain highly skilled subordinates who have the ability to cope with the complex battlefield? The issues related to skills are addressed by the explicit inclusion of training and simulation aids as part of the FCS program. However, the Army must lay the groundwork for personnel development

programs long before the future warfighting systems become available. Not doing so may lead to a force that is unprepared for high-intensity, advanced combat operations. Moreover, the Army must be willing to make organizational changes in response to the new strategy and tactics of network-centric warfare. It must also gear recruitment to attract the kind of soldiers capable of handling both the G.I. and "gee-whiz" aspects of the transformed Army.

Summary Assessment

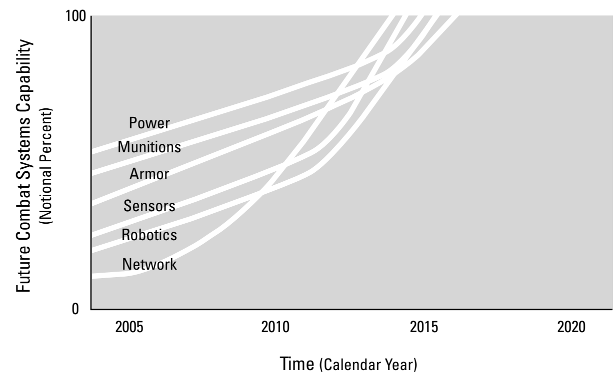
The Army's motivation for proposing the FCS is its return to relevancy. Since the FCS relies heavily upon technology, the degree of relevance obviously depends upon the capabilities of the technology. Technically, realization of the FCS follows an evolutionary path to a revolutionary vision. Although the timing of critical decisions can be justified on timeframes necessary to complete engineering, development, and research tasks, it leaves little room for error or experimentation. We feel that the technical issues are ones of focused engineering and not open-ended research. This does not imply that the problems to be overcome are simple, but that they are more likely to be overcome in time. The open-ended question is, how much time is needed? We have presented our estimates, but we admit there is considerable uncertainty.

The figure reflects our estimates of the maturity of the technologies examined and their applicability to the FCS. The shape of the curves is our notional assessment of how the technology will advance in the next decade. Relatively speaking, the most mature technologies are hybrid power, munitions, and armor, which are essentially products of the Industrial Revolution. Although advances in these areas will occur (in some instances via integration with electronic technology), their capabilities will increase at relatively slow and linear rates. Sensors and robotics are the most recent technologies growing out of the development of electronics in the late industrial period and early computer age. Their capabilities will grow exponentially due to their foundation in electronics and the impact of Moore's Law. The least mature technology is networks (a product of the Information Age). Its curve exhibits exponential growth around 2010. Predicting when the sensor, robotics, and networks technology will exhibit the nonlinear advancement to meet FCS requirements is at best an educated guess and the primary difficulty in managing the risk inherent in a high-technology program.

The performance of three technologies is critical to fully enabling the FCS concept: the network, munitions, and robotics. We have stressed that the network is critical to any realization of the FCS. Without it, the theoretical advantages of network-centric warfare cannot be validated. With present technology, it may be possible to network a single FCS unit cell but not an FCS unit of action or unit of employment. Similarly, present technology in munitions provides an effective line-of-sight fire; however, FCS is dependent upon Netfires to ensure its capability for beyond-line-of-sight fire. Finally, UAV technology is mature, and UAVs are expected to be a significant constituent of the FCS initial operational capabilities. UGV technology is less mature and may have only limited utilization in the initial operating capabilities.

In light of the figure, to address strategic concerns along with technological ones, it is best to consider a graduated application of

Notional Prediction of Advances in Technology and FCS Capability over Time



the FCS to its missions. The present technology indicates a level of capability appropriate for a rapid medium-force unit capable of engaging a mechanized opponent that is not a near-peer competitor. Given American overseas engagements over the last decade, the need for these units now and in the foreseeable future is great. A decision on a version of the FCS capable of effective involvement in a small-scale conflict could be made by 2010, and the decision on an MTW-capable FCS version by 2014. Thus, even if the FCS is unable to compete in an MTW within the next decade, the investment in FCS technology will have provided enhanced capabilities for an expeditionary force; with block upgrades, it may realize its fullest potential in its second decade of development.

Notes

[1] Alvin Toffler, *The Third Wave* (New York: Bantam Books, 1980).

[2] 2001 Army Science and Technology Master Plan, U.S. Department of the Army, Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology, January 2001.

[3] Ibid.

[4] "Technical and Tactical Opportunities for Revolutionary Advances in Rapidly Deployable Joint Ground Forces in the 2015–2025 Era," Army Science Board FY2000 Summer Study, April 2001.

[5] 2001 Army Science and Technology Master Plan.

[6] "Technical and Tactical Opportunities," Army Science Board.

[7] 2001 Army Science and Technology Master Plan.

[8] Ibid.

[9] Michael O'Hanlon, *Technological Change and the Future of Warfare* (Washington, DC: The Brookings Institution Press, 2000).

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